

NASA Case Study

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Sitting On The Fence: Launching A Balloon In The Outback

The NASA Balloon Program

The NASA Balloon Program Office¹ (BPO) has a long and successful history of launching balloons. Those Missions have obtained much scientific and technical data that has been instrumental in new discoveries over the past three A balloon Mission is one decades. thirtieth the cost of a Space Satellite Mission. Instruments carried on balloons have produced important scientific results, and many instruments developed initially for balloon flights have been used on Spacecraft. For instance, the Cosmic Background Explorer (COBE) and the Wilkinson Microwave Anisotropy Probe (WMAP)² Cosmic Microwave Background Explorer Missions were



Figure 1: Launch Configuration for the Nuclear Compton Telescope. Source: NASA Image.

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The Balloon Program is located at Goddard Space Flight Center's Wallops Flight Facility in Wallops, Virginia. The Program reports to the Astrophysics Division within the Science Mission Directorate at NASA Headquarters (HQ). Launches are conducted by the Columbia Scientific Balloon Facility (CSBF), a government-owned, contractor-operated facility located in Palestine, Texas. See **Appendix 1** for case references.

² See **Appendix 2** for a list of acronyms used in this case.

enabled by precursor balloon flights beginning in the 1970s. See **Figure 1** for the launch configuration of the Nuclear Compton Telescope.

Balloons continue to serve as a training ground for young Scientists and Engineers. Indeed, many leading Scientists, including Nobel laureates John Mather and George Smoot, gained invaluable early experience conducting balloon-borne science investigations.

"My thesis project at UC-Berkeley was a balloon payload to measure the spectrum of the cosmic microwave background radiation and it was an ideal preparation for the COBE, which later led to Goddard's first Nobel prize. As a student, I had to learn something about everything, from optical design to soldering. And I learned a great lesson about hardware: if you don't test it, it won't work, and this is not a matter of risk or chance, it's a certainty. I think that ballooning and sounding rockets are a wonderful introduction to space flight and, as in my case, have led to some spectacular discoveries."

John Mather, GSFC Project Scientist, Nobel Laureate Physics

The Balloon Program conducts a Mission portfolio of about 16 to 18 flights per year of conventional comprised flights of a few days and longduration balloon (LDB) flights at 38 k.m. of a few weeks using zero-pressure balloons. Recently, balloon newer designs have reached altitudes of nearly 50 k.m., and durations of about 60 days, making them even more useful to conduct fundamental scientific discoveries that contribute to our understanding of the Earth, the solar system, and the NASA's vision for universe. scientific ballooning centers on

the development of super-pressure balloons (SPB) which will enable 100 day flights of observatory class payloads from any latitude—effectively becoming "Satellites on a string".

History of the Nation's Scientific Balloon Program

The National Scientific Balloon Facility (NSBF) was established in Boulder, Colorado, in 1961 under the auspices of the National Science Foundation and moved to Palestine, Texas, in 1963. In 1982, NSBF was transferred to NASA. In October 1987, the NASA contract to operate the NSBF was awarded to the Physical Science Laboratory/New Mexico State University, in Las Cruces, New Mexico. In 2006, the National Scientific Balloon Facility was renamed the *Columbia* Scientific Balloon Facility (CSBF) in honor of *Columbia*'s crew.

How the Program Is Organized

NASA's Balloon Program is managed for the Science Mission Directorate (SMD) by the Balloon Program Office (BPO) at the Goddard Space Flight Center's Wallops Flight Facility, in Wallops, Virginia. Science payloads are selected competitively through proposals to SMD and funded by research and analysis (R&A) grants. The flights are conducted by the CSBF, a government-owned, contractor-operated (New Mexico State University) facility located in Palestine, Texas. NASA SMD approves the flight manifest annually. BPO administers the balloon operations contract for CSBF. Balloon ground and flight Safety is provided by Wallops Safety. Under the performance-based contract, the CSBF launch crew meets with the selected science team to establish requirements and to complete integration and test

activities using established interfaces. The CSBF launch crew conducts the launch according to NASA safety ground and flight safety plans.

How Balloons Work

NASA balloons that have been used to date for both conventional and Antarctic long-duration balloon (LDB) flights are zero pressure. They are vented near the bottom to the outside, so the balloon pressure is in equilibrium with the atmospheric pressure at that point (zero differential pressure). At night, without solar input, there is a cooling of the helium and consequent shrinking of the balloon volume, which causes the balloon to sink to a much lower altitude. To reduce the altitude variation at sunset, the payload must carry ballast (fine steel or sand grains) that can be dropped by radio command to lessen the



Figure 2: Launch at Sunrise from Sweden. Source: NASA Image.

suspended weight. (See **Figure 2** for a launch at sunrise from Sweden.) Limitations on the amount of ballast that can be carried limit the number of sunsets a balloon can survive, and the extent to which the diurnal altitude variation can be reduced. The longest duration flights can be flown during local summer over Antarctica or in the Arctic, where continuous sunlight permits the balloon to maintain altitude without the need to drop ballast.

Alice Springs International Airport, Northern Territory Australia

The town of Alice Springs³ was named after the wife of a Postmaster and the apparent spring in the bottom of the seasonally dry Todd River that meanders through the town. Alice Springs lies almost in the center of Australia and was initially an important rail and telegraph link. Later during WWII, an airport was set up and used as an important staging ground. In the 1960s, the area was used as a Satellite-Monitoring base mostly for defense Satellites, partly because of its remote location almost directly in the center of the Australia. The airport is big enough to handle jumbo jets, but not very many land there even though tourism for the near-by historical and geographical sites is the biggest industry.

³ For more information on the city of Alice Springs, see http://www.alicesprings.nt.gov.au/.

Launch Management

One aspect of balloon launches is that they can be done essentially anywhere in the world. That is an important consideration to take advantage of launch weather, as well as stratospheric wind patterns needed for the science requirements. Launches from mid-latitudes (such as Australia) offer wider sky coverage as well as greater observing opportunity for gamma-ray astrophysics payloads. The BPO has made its launching capability mobile, taking teams and equipment annually to Antarctica, Sweden, and Alice Springs. The BPO contracted with the New Mexico State University, Physical Sciences Laboratory through a contract to manage CSBF and to conduct balloon launches worldwide. CSBF provides a complete launch team, including a Launch Director (LD) and a Campaign Manager (CM). The University of New South Wales (UNSW) manages the Alice Springs Balloon Launch Station for CSBF under the direction of a Site Director (SD).

While launching a balloon is complicated, it uses some ordinary equipment. For launches from Australia, a crane is rented locally and configured as the launch vehicle. Helium is brought to the site in tankers. Other more specialized equipment for protecting the balloon as it is laid out on the ground and for releasing it is brought and deployed along with the locally obtained equipment. To ensure good value for the government and timely operations, the balloon launch contract is performance based. Much of the training is done on the job with minimal insight from NASA, as is appropriate for a performance-based contract.

The Nuclear Compton Telescope (NCT)

The instrument to be launched on this Mission was built by the University of California Berkeley. Similar instruments had been flown successfully in 2008, demonstrating high sensitivity, energy resolving gamma-ray detectors similar to the technology planned for the Advanced Compton Telescope Satellite for the 2020 decade. The NCT was designed to further advance our understanding of how we can measure gamma rays in preparation for the next big space-based Compton Telescope to be launched into orbit around 2020.

How to Launch a (really big) Balloon

Launching a balloon is quite complicated, though it almost always appears fairly routine for the over 2,500 launches CSBF has conducted. High-altitude balloons are made of very thin polyethylene film about the thickness of a freezer bag to be as light as possible yet strong enough to sustain float and payload. The balloon material is laid out on a protective cloth to keep it from tearing or snagging on the ground. Only a small portion of the balloon itself (the bubble) is filled with helium. The scientific payload (balloon craft) is connected to the balloon through steel cables and an unpacked parachute. Prior to launch, the payload is suspended from the modified crane using a steel plate attached to a pin.⁴ As the balloon ascends in altitude, the rest of the balloon fills out as the helium expands in the upper atmosphere. At launch, a collar is wrapped around the balloon below the launch spool so that when released, the balloon film is not torn as the flight train⁵ rises above the launch vehicle.

⁴ See Figure 3.

⁵ See Figure 4.

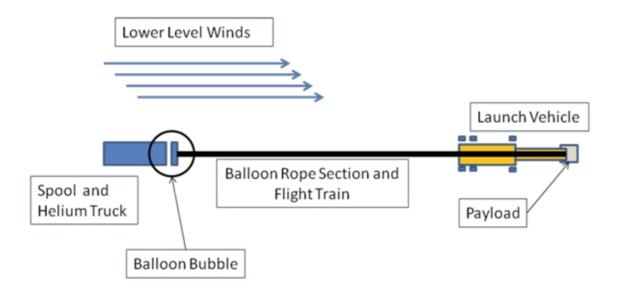


Figure 3: Balloon Layout Aligned with Lower-Level Winds. Source: Figure 14 of MIB Report.

To launch the balloon, the bubble is released and the whole balloon flight train (balloon bubble, balloon rope section, parachute, steel cables) and payload (still attached to the crane) achieves vertical alignment. It is the Launch Director's task to see that the train achieves this vertical alignment by maneuvering the Launch Vehicle (LV or mobile crane) as necessary, often chasing the balloon for a limited distance. When vertical, the balloon craft is released by a pin-release mechanism on the end of the crane and the balloon ascends. The bubble (pulling with a tremendous upward force) must be vertical over the crane launch vehicle in order to pull the balloon craft upward and not sideways (and thus risk contact with the ground). Clearly, wind conditions (strength and direction) are primary constraints given this launch process. Once the balloon bubble is filled with helium and the train is released, it is normally about 25 seconds to 30 seconds to launch release. This is called the dynamic launch process to indicate the fluidity of the situation during inflation and final release.

The NCT Launch Campaign

In the early hours of April 29, 2010, the Launch Team began to monitor the atmospheric conditions including wind direction and velocity in preparation for the NCT launch scheduled for later that day. Pilot balloons (small sounding balloons) were released starting at 2:18 a.m. More were released up to the launch time. A tethered balloon was also set up on the launch vehicle to indicate wind up to the 1,000 f.t. level. This was important to know since wind speed and direction determine any maneuvering the launch vehicle might have to do to position itself below the balloon when the balloon train is released. Balloon helium inflation commenced at 6:43 a.m., after determining that conditions were acceptable for a launch. Inflation was completed at 7:50 a.m. A final pilot balloon released just 10 minutes prior indicated a slight shift in wind more from the South. Local air traffic control requested a 10-minute hold to clear local air traffic and then the launch proceeded.

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⁶ See **Appendix 3** for a simplified case timeline.

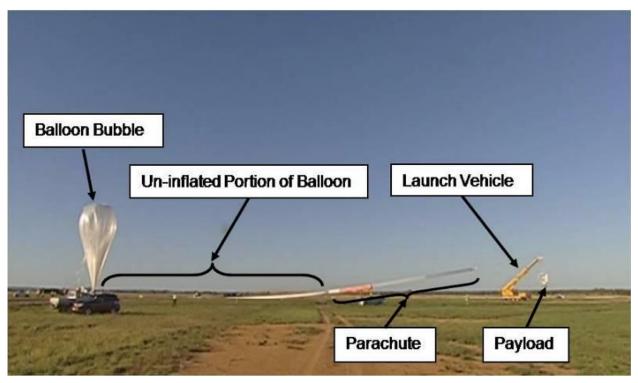


Figure 4: Balloon Configuration for Launch. The Photo Shows the Parts of the Balloon Train Ready for Launch. Source: Nuclear Compton Telescope Balloon Launch in Alice Springs, Northern Territory, Australia: High Visibility Type-B Mishap IRIS Case Number S-2010-119-00007 Volume I of II. Figure 9.

Spectators on the Fence

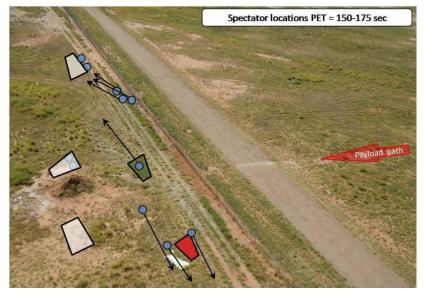


Figure 5: Spectator Location at PET 150 seconds to 175 Seconds. Source: Figure 24 of the MIB Report.

After the balloon bubble was inflated and just prior to spool release, the CSBF Launch Director (LD) noticed that there were spectators gathered downwind of the balloon's projected flight path. He requested over a radio that the spectators be moved. The UNSW SD responded and put out a general call over the radio for spectators to be moved. An off-duty CSBF crew member, who was among the spectators and the Deputy UNSW Site Director, heard the request. The crew member, located South of the flight eventual path, moved spectators to the North. The Deputy Site Director, located North of the eventual flight path, moved

spectators South. The confusion and the final wind shift placed many spectators directly in the launch line.

The spectators were either standing or in off-road vehicles up against an airport fence (not the airport perimeter). Usually, balloon launches did not go in that direction and they had determined it was a good viewing location to get some pictures of the launch. See Figure 5.

Pre-launch flight safety assessments only considered the ascent and over-flight phases, not the launch phase. The ground safety plan defined a hazard zone in which to layout and launch the balloon, but it was unclear whether it was fixed or moving.

Maneuvering the Launch Vehicle

Normally during a balloon launch, once the balloon train is vertical above the payload, the launch release pin is pulled and the balloon ascends vertically as the payload is pulled up and away from the launch vehicle. If, for some reason, it is not possible to launch the balloon, the Launch Director can maneuver the launch vehicle to get under the balloon and try again to release the payload and launch the balloon. Typically, this would mean driving downwind to chase the balloon and get back under it enough to be able to safely release the payload so it would directly rise avoiding any contact with the ground.

At 8:05 a.m., the launch spool was released to let the balloon flight train rise to the vertical orientation. The balloon rose quickly and because of the cross wind, drifted slightly to the North. Ten

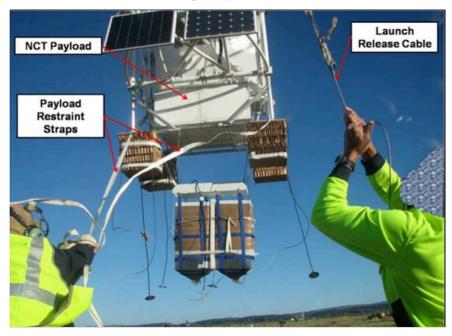


Figure 6: Actual NCT Launch Attempt. Source: Figure 20 in the MIB

seconds after spool release, the Launch Director instructed the launch vehicle to move in a Northwest arc to better align with the balloon prior to launch. After moving in this arc for 35 seconds, it became apparent to the Launch Director that the balloon was slightly ahead of the launch vehicle. The launch vehicle made a 90degree left turn to realign the vehicle with the projected flight path. Shortly after it made this turn. it became momentarily stuck in the soft ground. See Figure 6.

A few moments later, the LV came to a stop and the LD attempted to launch the balloon, but when he pulled on the lanyard to release the pin, it failed to release. The payload had started to swing and the LD attempted again to release the pin, but was unable to do so. The balloon continued to travel downwind

and the LD directed the LV to move again to catch up with the balloon for another launch attempt. About 15 seconds later, the launch vehicle came to a stop, because it had reached the perimeter fence where the spectators were located.

Abort, Abort, Abort

Recognizing the unsafe proximity to the spectators and that the LV could not proceed any further because of the fence, the LD directed the LV to move (backwards) away from the fence. He knew it would be unsafe to abort (release the balloon without the payload), because of the possibility that some of the balloon train would fall on the spectators. The LV backed away from the fence where it again became stuck in the soft ground. The Launch Director attempted a left turn to move to a safer position away from the spectators and the perimeter of the airfield to conduct an abort. He was attempting to set up the abort path to the side of the spectators. About a minute after the LV had originally reached the fence and the spectators and while it was attempting to turn left, restraint cables failed and the payload inadvertently released. Because of the catenary⁷ of the balloon, the payload was dragged on the ground through the fence, colliding with several spectator vehicles. Fortunately, the spectators were able to jump out of the way in time and no one was injured.

⁷ The catenary refers to a peculiar curve formed by a suspended cable-like combination, in this case, the balloon while it was still attached to the launch vehicle. See the MIB Report for a detailed analysis of the catenary.

Appendix 1

References

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NASA. Wallops Flight Facility. Available at http://www.nasa.gov/centers/wallops/home/index.html. Accessed on March 13, 2013.

Appendix 2

Case Acronyms

BPO	Balloon Program Office	
CM	Campaign Manager	
COBE	Cosmic Background Explorer	
CSBF	Columbia Scientific Balloon Facility	
HQ	Headquarters	
LD	Launch Director	
LDB	Long-Duration balloon	
LV	Launch vehicle	
NCT	Nuclear Compton Telescope	
NSBF	National Scientific Balloon Facility	
R&A	Research and analysis	
SD	Site Director	
SMD	Science Mission Directorate	
SPB	Super-Pressure balloons	
UNSW	University of New South Wales	
WMAP	Wilkinson Microwave Anisotropy Probe	

Appendix 3

Key Events of Timeline (simplified)

(The event numbers listed here are represented in the visual reference provided on the next page.)

<u>Time</u>	Name	<u>Description</u>
02:59:00 a.m.	Event 4	Pilot-balloon readings indicate winds resulting in LD determining a 110-degree
		balloon layout.
05:54:00 a.m.	Event 11	LD requests the balloon to be laid out for launch.
06:43:00 a.m.	Event 16	LD notices spectators in the downwind flight path and request their relocation.
07:50:00 a.m.	Event 21	Site manager requested air traffic control clearance to launch.
08:02:00 a.m.	Event 22	Clearance received from air traffic control for launch.
08:05:19 a.m.	Event 23	Spool released to launch balloon.
08:05:29 a.m.	Event 24	LD orders launch vehicle driver to drive forward making a sweeping right 90-degree turn.
08:06:04 a.m.	Event 27	Launch vehicle comes to a stop.
08:06:06 a.m.	Event 29	LD orders launch vehicle driver to turn left to align with balloon's flight path.
08:06:21 a.m.	Event 30	Vehicle slows down due to loss of traction and then speeds up to catch the balloon.
08:06:38 a.m.	Event 31	Launch vehicle breaches the Category-A hazard area.
08:06:46 a.m.	Event 34	First visible launch attempted by pulling on the release cable, NO JOY.
08:06:48 a.m.	Event 35	Second visible launch attempted by pulling on the release cable, NO JOY.
08:07:04 a.m.	Event 39	Launch vehicle stops at airport perimeter fence.
08:07:17 a.m.	Event 41	Launch vehicle starts moving in reverse.
08:07:47 a.m.	Event 42	Launch vehicle loses traction in soft dirt and cannot continue in reverse.
08:07:49 a.m.	Event 43	LD orders the launch vehicle driver to pull forward making a left 90-degree turn.
08:08:10 a.m.	Event 44	Safety restraint cables snapped.
08:08:10 a.m.	Event 45	Uncontrolled release of the NCT payload resulting in the payload impacting the ground, then a privately owned vehicle and nearly causing injury or death to public spectators. (undesired outcome)
08:08:10 a.m.	Event 46	Abort called.
08:08:16 a.m.	Event 47	Payload impacted the point of view.